

THE PETROLOGY OF THE CAINOZOIC BASALTIC ROCKS OF TASMANIA

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Introduction

Cainozoic basaltic rocks outcrop over an area of about 1,600 square miles, or about 6 per cent, of the land surface of Tasmania; and from the distribution of present outcrops it would appear that the basaltic magma from which they were derived underlay an area of perhaps 15,000 square miles. As may be seen from Fig. 1, they are most extensively developed in the north-west of the island, particularly in the triangular area extending westwards from Deloraine to Waratah and Preolenna. In this region they occur as a series of extensive lava fields^(13, 3) capping parts of the seaward sloping plateau surface that is known as the North-Western Peneplain.⁽¹⁹⁾ The plateau has been deeply dissected by streams flowing into Bass Strait, leaving the basalt as a flat capping, about 100 feet thick, on the ridges and broader plateau areas between the valleys. The surfaces of the basalt plains are diversified by the shallow valleys of streams that are as yet confined to the plateau surface (upland or hanging streams), and by occasional more or less conical hills marking points of eruption (Plate III, fig. 5). In places the plateau surface rises step-fashion across small scarps that trend parallel to the north coast. Further to the west there are extensive basaltic areas south of Smithton, and near Marrawah and Balfour.

Numerous areas of basaltic rock occur in eastern and central Tasmania, at varying elevation. These are commonly confined lava fields,^(13, 3) not extending beyond the interfluvies of the pre-basaltic valley into which the basalt erupted.

In the north-east such lava fields have infilled the old valleys of Pipers River and Pipers Brook, St. Patrick's River, the Little Forest Rivulet, Bessel's Rivulet, and the Ringarooma River. Small lava fields occur east of St. Leonards and between Perth and Breadalbane, fringed by small residuals. Basalt flows filling old valleys occur on the Central Plateau, in the vicinity of the Great Lake, Lake Sorell, and along the Nive River, and occur as small residuals capping a number of isolated hills along the margin of the Western Tiers. In the Midlands, basalts form broad plains in the old valleys of the South Esk and Macquarie Rivers, the latter field extending from Conara Junction to Tunbridge. Small conical hills, marking points of eruption, can be observed in the vicinity of Campbell Town, Conara Junction, and Fordon (south of Nile).

In the south-east, basaltic areas are found at Bridgewater, at Campania, in the valley of the Coal River, and near Sorell at the head of Pitt Water, and in the vicinity of Rokeby. Basaltic residuals occur at intervals along the valley of the Derwent at New Norfolk, Macquarie Plains, Hamilton, Glenora and at Ouse; and isolated small areas lie south of Hobart, near Kingston, Ranelagh and Hythe.

In addition several unusual differentiated basaltic types outcrop as small volcanic cones or plugs on Shannon Tier.

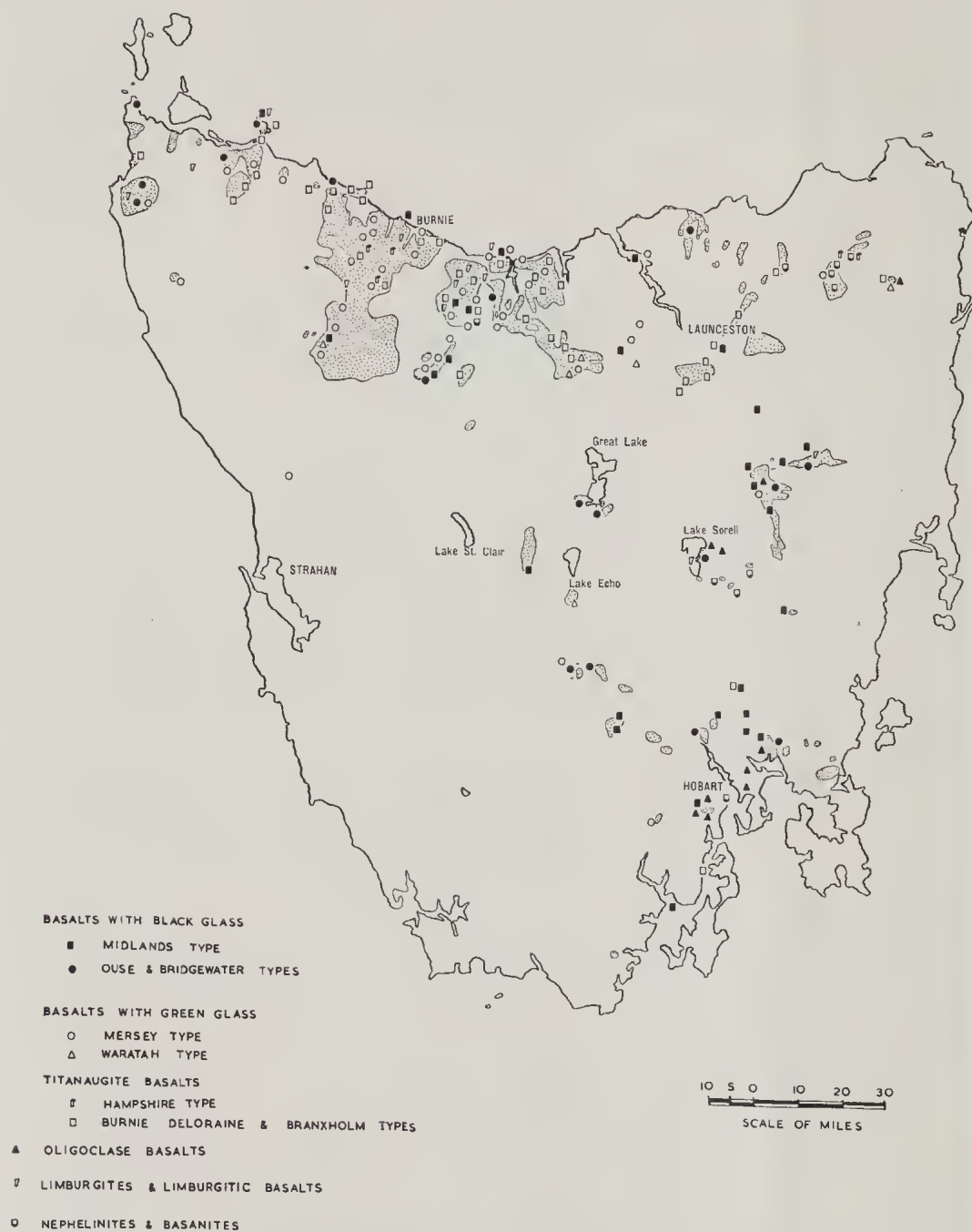


FIG. 1.—Relative distribution of Basalt Types in Tasmania.

Age of the Basalts

The age of the basalts is not everywhere well established. In the neighbourhood of Wynyard they overlie Miocene marine sediments, and in the vicinity of Launceston and Hobart they overlie leaf-bearing sediments of the Launceston Basin and the Derwent Basin, so that in these areas they are regarded as Pliocene or younger.⁽¹²⁾ A similar age has been assigned to most of the occurrences in eastern Tasmania,^(19, 3) chiefly on physiographic grounds.

A Miocene or pre-Miocene age has been established for certain basalts at Marrawah, in north-western Tasmania,⁽¹⁹⁾ and there is a tendency to correlate the basalts capping the dissected plateaux of the North-Western Peneplain (the Waratah and Middlesex Plains basalts), and the residuals of high level basalts along the margin of the Western Tiers, and at Bransholme and Weldborough, in north-eastern Tasmania, with these pre-Miocene basalts of Marrawah.

The Pliocene, or younger, basalts have been correlated tentatively with the basalts of the Newer Volcanic Series of Victoria, and the pre-Miocene basalts with the basalts of the Older Volcanic Series of Victoria.

Petrology

Previous Work

The earliest petrological study of Tasmanian basaltic rocks was made by Ulrich,⁽¹²⁾ who recognized the presence of olivine basalts among them, and also recorded a nephelinite (possibly one of the nepheline-bearing rocks of Shannon Tier). This early examination was amplified by the studies of Twelvetrees,⁽²⁴⁾ summarized in his statement of 1908, which records the prevailing types as 'basalts and olivine-basalts,' with occasional developments of limburgite and more alkaline types, as at Table Cape, Circular Head, Shannon Tier and Sandy Bay. No detailed account of these rocks was published, however. Auroousseau⁽¹⁾ analysed and described in detail the nepheline basanite of Sandy Bay; and Paul,⁽²⁰⁾ and later Erdmannsdorffer and Nieland⁽⁹⁾ and Tilley,⁽²²⁾ gave detailed descriptions and analyses of the melilite-bearing nepheline basalts of Shannon Tier. Brief petrological accounts of local basalt occurrences are recorded in several bulletins of the Geological Survey of Tasmania, notably Bulletin No. 41 (Smithton District), which includes two chemical analyses; and Edwards⁽⁶⁾ has described the differentiated crinanite laccolith of Circular Head (Stanley), with five chemical analyses.

This Paper

The object of this study was two-fold—(1) to provide a more detailed petrological account of the Tasmanian basaltic rocks, and (2) to discover whether any petrographic distinction can be drawn between supposedly 'Older' and 'Newer' basalts, such as obtains in Victoria.^(4, 5) It is based upon the examination of more than 300 specimens collected as 'grab samples' during a number of journeys designed to traverse most of the major and minor basaltic areas in Tasmania. It can be expected that this method of collecting has failed to include some of the rarer and more strongly differentiated rock types, which would normally be of small volume; but it has provided a reliable sample of the prevailing rock types, and so yields a picture of the petrological character of this basaltic province, from which the likely nature of strongly differentiated rock types that may occur, but are not represented in the collection, can be deduced.

Rock Analyses

Eleven new chemical analyses are presented. These were made by Mr. W. St. C. Manson and his associates, of the Mines Department Laboratory, Launceston, by permission of the Director of Mines for Tasmania, in connection with a study of the bauxites of Tasmania, which required as an integral part a knowledge of the petrological characters of the basaltic rocks.

THE ROCK TYPES

The rocks of the collection consist predominantly of a variety of olivine-basalts, with associated limburgites, limburgitic-basalts, olivine-nephelinites and nepheline-basanites, all clearly the differentiation products of an olivine-basalt magma type. The melilite-bearing nepheline basalts and fassinite of Shannon Tier so closely resemble the nephelinites and basanites that they must be included as more extreme differentiates of this magma. Other differentiated types are the oligoclase-basalts of the south-east, the highly feldspathic olivine-basalt of the Smithton district in north-western Tasmania, and the nepheline-bearing facies in the Circular Head laccolith. No acid or intermediate extrusives have been found, but if they occur they can be expected to be of a phonolitic or trachytic character. It is possible that the syenite-porphry stock of Port Cygnet and its related dykes⁽⁸⁾ are differentiates of this olivine-basalt magma, but the only evidence for this is a possible similarity in age between these rocks and some of the basalts, and the trachyte-like character of some of the dyke rocks.

Classification

The more differentiated rock types in the collection are easily distinguished microscopically and chemically, and are readily classified, but the basalts are more difficult to classify. Some of them are sufficiently distinctive in thin section to be grouped into types or varieties that recur in different parts of Tasmania. Descriptions of the characteristic features of these types are set out in the following sections, amplified by photomicrographs. Chemical analyses have been made of representative specimens, and the analyses show variations in chemical composition in keeping with the petrographical variations; but there are too few chemical analyses of any one type, or of related types, to establish the full significance of textural variations.

The bases of classification are three, and are given in the order of their apparent significance:

- (i) the *type of pyroxene* predominating, whether augite or titanaugite;
- (ii) the *texture of the groundmass*, whether ophitic, intergranular, or intersertal, and the relative proportions of felspar, pyroxene and glass, with especial emphasis on the *nature of the glass*, whether green or black;
- (iii) the nature and relative proportion of the phenocrysts, olivine, plagioclase and pyroxene.

On these bases, nine types of basalt have been established, as indicated in Table 1. For convenience of reference, each type has been given a distinguishing name, such as *Midlands Type*, or *Mersey Type*. The names derive from a district or locality in which the type is typically developed, and are intended for local use only. Some of the types are of wide occurrence, others are more restricted, as may be seen from Fig. 1, in which the location and classification of the specimens in the collection are shown.

TABLE 1

Petrographic Classification of the Widespread Types of Basalt in Tasmania.

GROUNDMASS		PHENOCRYSTS			SiO ₂ Content %
Type of Pyroxene	Texture	Olivine	Olivine + Pyroxene	Olivine + Plagioclase	
Absent or vestigial (colourless)	Intersertal, with abundant <i>black</i> glass	OUSE TYPE	—	—	50-51
Colourless augite	Intersertal to inter- granular, with abundant <i>black</i> glass	BRIDGE- WATER TYPE	—	—	50-51
Colourless augite	Ophitic to inter- granular, with or without a little <i>brown</i> or <i>black</i> glass	MIDLANDS TYPE	—	—	50-51
Colourless augite	Intersertal to inter- granular, mostly with some <i>green</i> glass	MERSEY TYPE	—	WARATAH TYPE	48
Titanaugite	Ophitic, medium to coarse-grained	DELOR- AINE TYPE	HAMP- SHIRE TYPE	—	44-45
Titanaugite	Ophitic patches, flow structure	BURNIE TYPE	—	—	44-45
Titanaugite	Intergranular	BRANX- HOLM TYPE	—	—	44-45

As might be expected, a number of specimens are intermediate between two or more types, and from such transitional relations it appears that there are three main groups of olivine-basalts in Tasmania:

- (1) *basalts with black glass*: Midlands Type, Bridgewater Type, Ouse Type;
- (2) *basalts with green glass*: Mersey Type, Waratah Type;
- (3) *basalts with titanaugite*: Hampshire Type, Deloraine Type, Burnie Type, Branxholm Type.

The close relationships of the members of these three groups is borne out by their similarities in chemical composition, as may be seen from the analyses of specimens selected as representative, in Tables 2, 3 and 4.

BASALTS WITH BLACK GLASS

Olivine-basalts containing more or less black glass comprise 20 to 25 per cent of the collection. Three related basalt types containing such glass can be distinguished. The three types are of similar chemical composition (Table 2) but are texturally distinct, though a gradation from one type to another can be traced, corresponding to a progressive crystallization of the glassy mesostasis.

Ouse Type

These rocks consist of corroded idiomorphic phenocrysts and microphenocrysts of fresh or serpentinized olivine, grading down to granules, and small laths of plagioclase, set in an abundant mesostasis of black glass (Pl. I, fig. 1). The plagioclase is labradorite, of a composition about An_{60} , and some crystals have hollow cores that have become filled with the black glass. The felspar laths generally show a random arrangement, but an exception is provided by a specimen from Marrawah, in which there is well marked flow alignment.

The glass, when resolved under high magnification, is found to consist of myriads of minute granules of iron ore in a brownish glass, which is traversed by feathery 'ghosts' or skeletal crystals of pyroxene and felspar. Occasional patches of green glass (brown in some weathered specimens) occur in the black glass, and calcite may accompany such green glass. In some specimens, particularly those from Ouse, the skeletal crystals of pyroxene and felspar in the black glass occur as curving sheaves of microlites that form a striking dendritic pattern (Pl. I, fig. 1). These sheaves have been termed *keranoids*⁽²⁵⁾ and *sphaerokrystalle*.⁽¹⁰⁾

An analysis of a representative specimen from Ouse is given in Table 2, No. 1. The chief features of the analysis are the high SiO_2 content, as compared with the titanaugite-basalts (Table 4), the lower magnesia content, MgO and CaO being in about equal proportions, and the low potash content. Titania and phosphorus also tend to be low.

TABLE 2
Analyses of Basalts with Black Glass in the Base

	1.	2.	3.	A.	B.
SiO_2	51.48	51.48	50.04	50.44	49.86
Al_2O_3	14.32	14.18	14.47	14.47	14.35
Fe_2O_3	2.17	1.56	4.26	6.32	4.21
FeO	8.98	9.61	7.69	5.01	7.02
MgO	8.02	8.18	7.89	7.93	8.25
CaO	8.33	8.95	9.35	8.75	8.45
Na_2O	2.48	2.61	2.47	2.59	2.80
K_2O	0.61	0.82	0.26	1.11	1.23
H_2O+	0.58	1.00	1.43	0.60	—
H_2O-	1.54	0.24	0.52	0.60	—
CO_2	0.05	tr.	tr.	nil	0.04
TiO_2	1.45	1.60	1.55	1.80	1.62
P_2O_5	0.21	0.29	0.23	0.31	0.38
MnO	0.14	0.15	0.17	0.19	0.18
Cl	nil	tr.	tr.	nil	—
SO_3	nil	tr.	tr.	nil	—
	<hr/> 100.16	<hr/> 100.67	<hr/> 100.33	<hr/> 100.12	<hr/> —

1. Ouse Type, glassy olivine-basalt (Pl. I, fig. 1), from near Ouse township. *Analyst*: W. St. C. Manson.
2. Bridgewater Type, olivine-basalt with intersertal black glass, from 400 yards upstream above bridge, Bridgewater township (Pl. I, fig. 2). *Analyst*: W. St. C. Manson.
3. Midlands Type, iddingsitized olivine-basalt, with a tendency to black intersertal glass, from Viney's Sugarloaf, at Fordon No. 22 lateritic bauxite deposit, south of Nile (Pl. I, fig. 3). *Analyst*: W. St. C. Manson.
- A. Iddingsitized olivine-labradorite-basalt (Footscray Type), from the Newer Volcanic Series, municipal quarry, Warrnambool, Victoria (Edwards, Ref. 5, p. 209).
- B. Average of 16 olivine-labradorite-basalts, from Newer Volcanic Series of Victoria (Edwards, Ref. 5, pp. 209, 284).

Bridgewater Type

With a slight increase in crystallinity, the potential augite in the black glass of the Ouse basalts appears as uniformly distributed granules, and the black glass is restricted in amount, so that the appearance of the rock in thin section is quite changed (Pl. I, figs. 2, 3), despite the fact that there is little or no change in chemical composition, as may be seen by comparing Analyses 1 and 2 of Table 2. The resultant rock consists of phenocrysts of olivine, which are commonly slightly resorbed, in an intersertal groundmass of plagioclase laths, augite granules and black glass. In some specimens a proportion of the felspar laths are sufficiently developed to appear as microphenocrysts. The pyroxene tends to be brownish, and has a positive optic axial angle of more than 45° , indicating that it is augite.

This variety of basalt is widely distributed throughout Tasmania (Fig. 1). The occurrence at Bridgewater was selected as typical and conveniently available. An analysis of a specimen from this locality (Table 2, No. 2) shows that it is a silica-rich basalt, practically identical in composition with the analysed Ouse basalt.

Midlands Type

This basalt type, named from its widespread occurrence in the Midlands region, represents the product of more or less complete crystallization of the black glass. The rocks are commonly grey, and finely vesicular, and consist of phenocrysts of olivine in an intergranular groundmass of labradorite laths, brownish augite of varying coarseness of grain size, but generally granular and ophitic or sub-ophitic towards the felspar laths, and lath-shaped crystals of ilmenite. In some specimens the granular augite crystals have become 'welded' into larger ophitic plates, but this is not common. A little dark glass is commonly preserved in the interstices, but is absent in some specimens. The olivine phenocrysts commonly have a narrow rim of iddingsite, but this is not always developed. The appearance of a typical specimen in thin section is shown in Pl. I, fig. 4.

The basalt outcropping at Viney's Sugarloaf, a distinctive small point of eruption close to Fordon, was selected for analysis. This Sugarloaf is just west of the road from Nile to Conara, about midway between Nile and the bridge over the South Esk. Its close resemblance in composition to the Ouse and Bridgewater basalts is apparent (Table 2, No. 3). The higher Fe_2O_3 content of the Viney's Sugarloaf rock reflects the partial conversion of the olivine phenocrysts to iddingsite. The low K_2O is possibly abnormal.

Comparison with Victorian Basalts

As may be seen from Table 2, this group of basalts, the Ouse, Bridgewater and Midlands Types, closely resembles in chemical composition the widespread Footscray type of the Newer Volcanic Series of Victoria. In the case of the Midlands basalts, the resemblance extends to the microtexture and mineral composition, the alteration of the olivine to iddingsite, the presence of black glass, and the grey colour and vesicular character of hand specimens. The Ouse basalts cannot be matched in Victoria, but occasional flows in Victoria resemble the Bridgewater type.

BASALTS WITH GREEN GLASS

Two closely related types of olivine-basalt, with green intersertal glass, and differing chiefly in the nature and proportion of their phenocrysts, are strongly developed in northern Tasmania (Fig. 1).

Mersey Type

This type of basalt is widespread, particularly in the region between Deloraine, Waratah and Preolenna. It consists of idiomorphic to slightly corroded phenocrysts of olivine, set in a groundmass of stumpy plagioclase laths, lath-like iron ores (ilmenite), granular, colourless to pale-brown augite, and pale-green glass, which resembles serpentine when devitrified. The texture is intergranular to intersertal, depending on the proportion of glass present, and the grain size of the groundmass varies somewhat. In the coarser-grained varieties (Pl. I, fig. 5) the olivine phenocrysts are about 0.5 to 1 mm. across, the smaller size being the more common. They have 2V about 90°, and are optically positive (in some instances negative), so that their composition is about Fo₈₅. They commonly show partial alteration to serpentine, the serpentine developing along fractures and around the margins of the crystals. In some sections there are occasional phenocrysts of labradorite, and somewhat inchoate phenocrysts of augite, marking a transition to the Waratah type of basalt, described below.

The groundmass plagioclase is a labradorite, with a maximum extinction angle in the symmetrical zone of about 33°, indicating a composition of about Ab₃₅. It occurs as laths 0.1 to 0.15 mm. long and 0.01 mm. thick. In some specimens the laths show a sub-parallel arrangement, as a result of flow. More often, however, they show random orientation. The iron ore laths, chiefly ilmenite, or ilmenite with intergrown lamellae of magnetite, are about 0.1 mm. long, and the pyroxene granules are about 0.05 mm. across, some of them prismatic. In some specimens, particularly those with flow texture, the pyroxene granules tend to form fringes around the olivine phenocrysts; and in some of the coarser-grained rocks they have coalesced to form inchoate phenocrysts, or coarser grains that tend to be sub-ophitic towards the felspar.

TABLE 3
Analyses of Basalts with Green Glass in the Base

				1.	2.	A.
SiO ₂	..	..	..	48.28	48.40	47.54
Al ₂ O ₃	..	..	..	14.01	15.59	14.16
Fe ₂ O ₃	..	..	..	3.13	5.12	3.02
FeO	..	..	..	8.45	6.29	8.89*
MgO	..	..	..	9.18	6.52	8.86
CaO	..	..	..	9.35	7.95	9.18
Na ₂ O	..	..	..	2.96	2.69	3.25
K ₂ O	..	..	..	0.89	1.09	1.88
H ₂ O+	..	..	..	1.29	2.40	0.55
H ₂ O-	..	..	..	0.40	1.74	1.47
CO ₂	..	..	..	0.06	tr.	nil
TiO ₂	..	..	..	2.10	1.88	0.90
P ₂ O ₅	..	..	..	0.39	0.36	0.44
MnO	..	..	..	0.15	0.14	0.30
Cl	..	..	..	tr.	tr.	0.06
SO ₃	..	..	..	tr.	tr.	nil
BaO	..	..	..	—	—	0.03
				<hr/> 100.66	<hr/> 100.17	<hr/> 100.63

1. Mersey Type, olivine-basalt, from outcrop on beach, east side of Mersey Bluff, east of Recreation Reserve. (Pl. I, fig. 5.) *Analyst*: W. St. C. Manson.
2. Waratah Type, olivine-labradorite-basalt, north end of Waratah township. (Pl. I, fig. 6.) *Analyst*: W. St. C. Manson.
- A. Trentham Type, olivine-basalt, allotment 79, parish of Trentham, Victoria (Newer Volcanic Series). (Edwards, Ref. 5, p. 284.)

Green glass is present in varying amount in the interstices. In a few specimens the iron ores have not crystallized completely, and the green glass is studded with globules and trichytes of iron ore that give it a dark appearance under low magnification. In some of the finer-grained specimens of this type of basalt, the pyroxene appears rather more abundant in the groundmass than is the case with the coarser-grained basalts, and the iron ores occur as squarish crystals, indicating that they are predominantly magnetite.

The basalt outcropping at sea-level on the east side of Mersey Bluff, near Devonport, which is a moderately coarse-grained variety (Pl. I, fig. 5), was selected as typical, and an analysis was made of this rock (Table 3, No. 1). Comparison of this analysis with those of Table 2 indicates that the Mersey basalts, though generally similar in composition to the group of basalts with black glass, contain somewhat less silica, and slightly more magnesia, soda and phosphorus.

Waratah Type

Closely related to the Mersey Type, and occurring in the same regions, but to a more limited extent, is the Waratah Type of basalt. This differs from the Mersey Type in the presence in it of phenocrysts of labradorite, as laths up to 1.0×0.2 mm., in about the same abundance as olivine, and occasional phenocrysts of pale-brown augite, from 0.25 to 1 mm. across. The augite is optically positive, with 2V about 50° , and tends to occur in small clots, associated with olivine phenocrysts (Pl. I, fig. 6). Some augite phenocrysts are inchoate, and appear to result from the 'welding' together of small granular crystals of augite, such as occur in the groundmass.

The basalt outcropping at the northern end of Waratah township was selected as typical, and a chemical analysis of this rock is given in Table 3, No. 2. It closely resembles the Mersey Type in composition, but has a somewhat higher Al_2O_3 and lower MgO content, corresponding to the greater abundance of feldspar and the lesser amounts of olivine and augite in this rock.

Comparison with Victorian Basalts

The Mersey basalt has an almost identical counterpart in the Trentham basalt of the Newer Volcanic Series of Victoria, though, as may be seen from the analyses of Table 3, the Victorian rocks tend to be richer in potash and poorer in titania than their Tasmanian equivalents. The Mersey basalt also bears a considerable resemblance to the Flinders basalt of the Older Volcanic Series of Victoria.

The Waratah basalt bears a general resemblance to the Gisborne basalt of the Newer Volcanic Series in Victoria, the Gisborne basalt being related to the Trentham basalt much as the Waratah basalt is to the Mersey Type. The Gisborne basalt tends, however, to contain a little hypersthene, a feature not noted in the Waratah basalt.

Comparison of the analyses of Table 3 with those of Tables 2 and 4 indicates that these basalts with green glass have a chemical composition intermediate between those of the basalts with black glass, and the titanaugite basalts.

BASALTS WITH TITANAUGITE

Basalts containing titanaugite are strongly developed in northern Tasmania—at Branhholm, Scottsdale, Derby and Weldborough in the north-east; near Perth, Longford, Deloraine, Harford and Latrobe in the centre; and in the Burnie, Smithton and Wynyard districts in the north-west—but they do not occur to any

extent in the Midlands or in the south-east. They are commonly associated with Mersey and Waratah basalts.

Five types of titanaugite basalt may be recognized on the basis of recurrent textural differences, but the chemical analyses available of these types (Table 4) show that with the exception of the Smithton type they are practically identical in composition. Presumably the textural differences are related to degree of crystallization prior to extrusion, to the rate of chilling after extrusion, and to variation in content of water and other variables, as indicated by the presence of analcite in some types.

TABLE 4
Analyses of Basalts with Titanaugite

	1.	2.	3.	4.	A.	B.
SiO ₂	44.12	45.44	43.76	43.35	44.91	45.86
Al ₂ O ₃	13.94	14.52	13.55	13.50	13.77	13.19
Fe ₂ O ₃	2.60	1.27	3.90	2.62	5.28	2.82
FeO	8.98	10.68	7.20	10.94	5.81	8.61
MgO	11.43	11.12	10.24	11.84	12.19	10.58
CaO	9.40	8.23	8.28	9.85	8.56	9.09
Na ₂ O	2.83	2.95	1.70	3.02	1.73	2.44
K ₂ O	1.99	1.41	0.47	1.18	0.94	1.00
H ₂ O+	0.10	0.32	6.68	0.15	3.40	1.33
H ₂ O-	1.94	2.62	2.06	1.74	1.34	1.66
CO ₂	tr.	tr.	tr.	nil	tr.	0.60
TiO ₂	2.30	1.83	1.63	2.25	7.73	2.20
P ₂ O ₅	0.55	0.40	0.35	0.71	0.32	0.51
MnO	0.14	0.14	0.12	0.11	0.33	0.24
Cl	nil	nil	tr.	—	nil	tr.
SO ₃	nil	nil	0.15	—	nil	nil
	100.32	100.56	100.09	100.34	100.39*	100.16**
					*NiO 0.03 CoO tr. Cr ₂ O ₃ 0.05	**NiO 0.03

1. Hampshire Type, olivine-titanaugite-basalt (Pl. II, fig. 1), with macro-phenocrysts of titanaugite, 3 to 5 mm. diameter, from prominent point of eruption east of Emu Bay railway line, a short distance north of Hampshire Railway Station. *Analyst*: W. St. C. Manson.
2. Burnie Type, olivine-titanaugite-basalt (Pl. II, fig. 2), from road cutting above Burnie Park (south of), Burnie. *Analyst*: W. St. C. Manson.
3. Deloraine Type, olivine-titanaugite-basalt (Pl. II, fig. 3), from core of a somewhat weathered boulder enclosed in deeply weathered material, road cutting at sharp bend midway between Deloraine and Elizabeth Town. *Analyst*: W. St. C. Manson.
4. Olivine-titanaugite-basalt from 70 ft. above the chilled base (olivine enriched layer) in the Circular Head laccolith. (Edwards 1941, p. 407.)
- A. Mirboo Type, basalt, Older Volcanic Series of Victoria, from Berry's Creek Bore No. 20, depth 90 ft., allot. 34, parish of Mardan, Victoria. (Edwards, Ref. 4, p. 90.)
- B. Camperdown Type, olivine-labradorite-basalt, Newer Volcanic Series of Victoria, from Harvey's Well, top flow, allot. 26, parish of Colongulac, Victoria. (Edwards, Ref. 5, p. 288.)

Hampshire Type (Titanaugite Porphyries)

Distinctive coarsely porphyritic titanaugite-olivine-basalts occur as a point of eruption and flow from it on the east side of the railway line just north of Hampshire railway station (Pl. III, fig. 5); as a flow at a point about six miles from Somerset on the road from Somerset to Yolla; as a flow about six and a half

miles from Burnie on the road to Ridgely; and at Mara, in north-eastern Tasmania. Related rocks, in which the titanite is ophitic rather than phenocrystic, occur on the road from Deloraine to Devonport at 33 miles from Launceston, and at Main Creek, near Derby.

In the Hampshire, Mara, Yolla and Burnie rocks the titanite is present as phenocrysts 5 mm. or more in diameter. These phenocrysts are composite rosettes, in which the individual crystals show idiomorphic outlines, with re-entrant angles towards the groundmass, and allotriomorphic faces towards one another (Pl. II, fig. 1). Small inclusions of olivine and plagioclase have been caught up as inclusions during the growth of the clusters. The titanite is strongly zoned, as many as 30 narrow zones being present in a single crystal. It is optically positive, with $2V$ greater than 45° , and is strongly pleochroic with X = deep violet, Y = pale violet, Z = light yellow.

Associated with the titanite phenocrysts are smaller idiomorphic or rounded phenocrysts of olivine, and micro-phenocrysts of magnetite, some of which have skeletal forms. The phenocrysts are set in a variable proportion of fine-grained groundmass, with an intergranular to intersertal texture, consisting of short plagioclase laths, granules of titanite, skeletal iron ore, apatite needles and colourless to greenish felspathic glass. The plagioclase is labradorite, of composition about Ab_{40} . The Burnie and Yolla specimens have fewer titanite phenocrysts than the other two, but have more and coarser crystals of titanite in their groundmass.

The rock from between Deloraine and Devonport contains very little olivine, and in this rock the abundant zoned, purple titanite occurs in clusters of crystals which are optically intergrown with plagioclase laths about 0.5 mm. long. The iron ore is coarse-grained, and scattered through an abundant glassy base, which is studded with myriads of fine skeletal rods of iron ore, oriented in parallel or rectangular growths, or in triangular lattices. Associated with the groundmass are occasional small flakes of red biotite, pleochroic to straw yellow.

The Derby rock is ophitic, but in it both the titanite and the labradorite occur as crystals 2 to 3 mm. across, optically intergrown with one another. Olivine occurs only as occasional corroded phenocrysts, much smaller than the plagioclase and titanite grains, and there is only a small proportion of fine-grained groundmass. This consists of small plagioclase laths, skeletal rods of iron ore, apatite needles, titanite, and a greenish glass felted with microlites of feldspar. The glass is sodic, since titanite associated with it is fringed with green aegirine-augite.

These rocks bear some resemblance to specimens of analcite-olivine-titanite-dolerite from the Table Cape and Circular Head laccoliths.

A chemical analysis of the Hampshire rock is shown in Table 4, No. 1. It is distinctly undersaturated with respect to silica, and has a rather low alumina content. This, together with the high MgO , CaO and TiO_2 , reflects its richness in titanite and olivine. The potash content of this rock is unusually high for Tasmanian basalts so far analysed. Presumably the felspathic glass is potassic.

Burnie Type

Basalts of this type are prominently developed in the vicinity of Burnie, Somerset and Seabrook, and in the vicinity of Harford, Sassafras and Latrobe. They consist of rounded phenocrysts of olivine, set in a relatively fine-grained groundmass, consisting of small olivine granules, narrow laths of plagioclase, abundant purple titanite, coarse iron ores, coarse needles of apatite, a little

felspathic glass and, in some instances, some analcite. The plagioclase is labradorite, about Ab₄₀, and the titanaugite is strongly pleochroic from deep violet to pale straw with a positive optic axial angle greater than 45°. The distinctive features of this group of rocks is the characteristic occurrence of the titanaugite as isolated, more or less lens-shaped patches, which are in intimate ophitic intergrowth with sheaves of narrow sub-parallel plagioclase laths (Pl. II, fig. 2). The titanaugite areas show up strikingly when viewed with crossed nicols.

Where analcite is present in any abundance it occurs in interstitial patches, and has replaced the felspar in part. Such rocks approximate to crinanite-basalts.

The excellent exposure of fresh rock in the cutting on the road that rises above Burnie Park on its south-east side, at Burnie West, was selected as the type locality, and an analysis was made of this rock. The analysis (Table 4, No. 2) closely resembles that of the porphyritic Hampshire basalt. The slightly higher SiO₂ and Al₂O₃, and lower CaO suggest that it contains slightly more felspar and less titanaugite than the Hampshire rock, but the differences are not very significant.

Deloraine Type

This variety of basalt may be regarded as a coarse-grained variation of the Burnie Type (Pl. II, fig. 3). The olivine phenocrysts tend to be larger and more clustered than in the Burnie Type, and the ophitic titanaugite is gathered into larger crystals, with fewer intergrown felspar laths. Moreover, the felspar laths in the ophitic intergrowths lack the parallel orientation of their counterparts in the Burnie basalts, as may be seen from a comparison of the photomicrographs of Pl. II, fig. 2, and Pl. II, fig. 3, which are of the same magnification. As a result, the colourless patches of groundmass, consisting chiefly of plagioclase laths, appear larger and more prominent in the Deloraine basalts.

An analysis of a slightly weathered specimen of the Deloraine Type—selected for analysis in connection with a study of the weathering of Tasmanian basalts in relation to the origin of bauxites, rather than for the purpose in hand—is shown in Table 4, No. 3. When allowance is made for its weathered condition, its close resemblance to the analyses of the Burnie and Hampshire Types is apparent. An analysis of a fresher example of a basalt of this type is provided by that of the olivine-enriched layer in the Circular Head laccolith (Table 4, No. 4). This analysis is somewhat richer in iron oxides, but closely resembles the others of this group, and in particular that of the Hampshire Type.

From these similarities it is apparent that there is little if any significant difference in the mineral composition of these three rock types. The difference is only in texture, and this is a reflection of the conditions attending the crystallization of the titanaugite. In the Burnie rock the titanaugite had scarcely begun to crystallize when extrusion occurred. The titanaugite crystallized ophitically about the felspar laths after extrusion had occurred, so that the flow alignment of the felspar laths is incorporated in the ophitic patches. Even so, cooling was sufficiently slow to permit considerable diffusion, or else the lens-like crystals of titanaugite could not have formed. In the Deloraine rocks the titanaugite apparently crystallized prior to extrusion, so that the felspar laths included in the ophitic areas show no flow alignment, and are fewer, though not necessarily larger. The slower onset of crystallization permitted freer diffusion in the melt, with correspondingly fewer centres of crystallization and larger growth of individual titanaugite crystals, making for larger interstitial areas of predominant felspar.

In the Hampshire rocks the crystallization of the titanaugite either commenced at a higher temperature or, more probably, the period between initiation of its crystallization and extrusion of the magma was longer. As a result of prolonged free diffusion in the melt the clusters of early-formed titanaugite crystals were able to grow large, pushing aside, rather than incorporating, the olivine and felspar crystals in the melt, except where these were trapped between adjacent titanaugite crystals. After the individual crystals of the clusters came into contact, their external surfaces continued to grow freely, forming glomeratic macrophenocrysts bounded by crystal faces, with more or less obtuse re-entrant angles between individual crystals of the cluster. The high CaO content of the Hampshire rock suggests that there was some gravitative concentration of the augite during the period prior to extrusion, and the prominent zoning points to their being carried about by convection currents during their period of growth.

These three basalt types can be regarded, therefore, as closely related variants of the same magma, deriving their textural differences from different lengths of cooling prior to extrusion. As might be expected, there are titanaugite basalts transitional between these types. The Burnie Type might be expected to approach most closely in composition to the source magma.

Branxholm Type

Where conditions, presumably rate of cooling, inhibited diffusion, myriads of crystallization centres developed, as cooling forced on crystallization, and basalts with intergranular textures resulted, in which the titanaugite is restricted to minute prisms and granules, with only an incipient tendency to form ophitic intergrowths with the felspar laths. In such rocks the groundmass appears darker from the even distribution of the pyroxene through it. Olivine-titanaugite-basalts of this texture, and with varying coarseness of grain size, are common in northern Tasmania, particularly in the vicinity of Harford. In some specimens the titanaugite occurs in part as microphenocrysts. With decrease in titanium content, they grade insensibly into the basalts of the Mersey Type.

In some of these intergranular titanaugite basalts the plagioclase laths occur partly as microphenocrysts, when the rock becomes a titanium-rich equivalent of the Waratah Type. There is also a tendency in these rocks for the small titanaugite prisms to form clusters and rosettes (Pl. II, fig. 4). Basalts with this habit are developed at Branxholm and Scottsdale in the north-east, at Longford, and near Wesley Vale.

An unusually coarse-grained variant (Pl. II, fig. 5) occurs about seven miles west of Wynyard, on the road to Stanley. In this rock the individual felspar laths are 2 to 3 mm. long, with some tendency to occur in sheaves. The felspar is somewhat analcitized, and there are interstitial areas of colourless glass and analcite, together with a little green chloritic material, and skeletal crystals of iron ore.

Smithton Type

An olivine-basalt of unusual composition occurs as the lowest of three flows in the Smithton district.⁽¹⁸⁾ It consists of phenocrysts of olivine in a relatively coarse-grained groundmass of ophitic titanaugite plates and laths of plagioclase, coarse iron ores, and a little feldspathic glass. In thin section the rock appears as a somewhat coarse and feldspathic variant of the Deloraine Type, but two chemical analyses (Table 5, Nos. 1 and 2) reveal that the rock has an extremely high alumina content, with a correspondingly high content of lime and alkalis, and a

remarkably low magnesia content. It is clearly a differentiated variety, but one not matched by known basalts elsewhere in Tasmania. The nearest approach to it so far recorded is the rock at the summit of the Circular Head laccolith, but this rock contains more magnesia and less alumina. It appears to represent a magma from which olivine has largely crystallized and sunk, without sufficient accumulation of soda to transform the residue into an oligoclase-basalt or mugearite.

The basalts overlying this felspathic basalt are of the normal types found in north-western Tasmania, including the Mersey Type.

TABLE 5
Analyses of Differentiated Titanaugite Basalts

			1.	2.	3.
SiO ₂	..	..	44.48	43.68	46.15
Al ₂ O ₃	..	..	20.60	21.18	18.95
Fe ₂ O ₃	..	..	5.98	1.42	3.68
FeO	..	..	7.38	11.45	6.41
MgO	..	..	3.73	3.90	5.20
CaO	..	..	8.10	8.85	9.15
Na ₂ O	..	..	2.67	2.51	3.79
K ₂ O	..	..	2.01	1.71	2.43
H ₂ O+	..	..	}	}	0.20
H ₂ O-	..	..			1.49
CO ₂	..	..	nil	nil	nil
TiO ₂	..	..	1.80	1.80	1.65
P ₂ O ₅	..	..	0.51	0.44	0.50
MnO	..	..	0.91	2.04	0.10
Cl	..	..	—	—	—
SO ₃	..	..	—	—	—
			99.76	100.69	99.70

1. Smithton Type, olivine-basalt, Myrtle Hill, east of Irishtown, Smithton District, probably from the base of the third flow. (Nye *et al.*, Ref. 18, p. 76.)
2. Smithton Type, olivine-basalt, Lileah, Smithton District, probably from the top of the third flow. (*Ibid.*, p. 76.)
3. Differentiated basalt from the summit of the Circular Head laccolith, Stanley. (Edwards 1941, p. 407.)

DIFFERENTIATED BASALTIC ROCKS

Oligoclase-basalts

Fine-grained oligoclase-basalts, of rather unusual chemical composition, occur at a number of localities in south-eastern Tasmania, namely, at Sorell, Cambridge, Rokeby, between Rokeby and Bellerive, at Kingston, between Kingston and Margate, and between Kingston and Longley. These may for convenience be called the Rokeby Type. They consist of idiomorphic phenocrysts of olivine completely altered to iddingsite, with occasional larger phenocrysts in which the iddingsite forms a rim round more or less completely altered olivine, set in a fine-grained groundmass of plagioclase laths and microlites, prisms of brownish pyroxene, abundant small and uniformly distributed granules or octahedra of iron ore, small granules of iddingsite, and some colourless glass (Pl. II, fig. 6). The plagioclase shows almost straight extinction when present as microliths, and a maximum extinction angle of 15° when present as laths, so that it probably has a composition on the borderline between oligoclase and andesine, of about Ab₇₀. A specimen from Rokeby contains a small clot of relatively coarse crystals of labradorite and pyroxene, while one from Kingston contains an inclusion of a fine-grained basaltic rock with corroded but fresh crystals of olivine.

TABLE 6
Analyses of Differentiated Basaltic Rocks

	1.	A.	2.	3.	4.	5.	6.	7.	8.
SiO ₂	46.64	45.10	42.44	42.44	39.12	36.17	36.03	37.60	38.35
Al ₂ O ₃	13.22	12.86	12.48	10.24	10.29	11.88	15.19	15.27	10.92
Fe ₂ O ₃	9.81	5.66	9.93	4.38	6.03	11.37	5.94	5.58	8.29
FeO	4.16	7.10	2.84	8.79	8.44	4.17	9.55	6.72	—
MgO	7.01	8.56	4.71	14.25	14.03	14.22	8.60	4.78	6.39
CaO	7.33	9.10	8.26	7.75	10.40	11.54	15.52	14.06	22.48
Na ₂ O	4.11	3.99	5.51	4.18	3.33	5.38	4.23	3.76	7.62
K ₂ O	1.35	1.02	3.16	1.83	1.23	2.07	1.85	0.87	2.55
H ₂ O+	0.52	1.53	1.64	0.18	0.88	—	—	5.61	—
H ₂ O—	2.14	1.10	1.73	1.32	2.46	—	0.58	1.15	—
CO ₂	tr.	tr.	nil	0.36	tr.	—	—	nil	—
TiO ₂	2.50	3.50	2.10	2.50	2.73	2.15	1.13	3.78	—
P ₂ O ₅	1.00	1.00	1.65	1.61	1.25	0.84	1.38	0.98	1.33
MnO	0.19	0.08	0.16	0.18	0.18	tr.	0.17	0.28	—
Cl	tr.	tr.	0.16	nil	nil	—	—	0.28	—
SO ₃	nil	nil	—	tr.	tr.	—	—	—	—
ZnO	—	—	nil	—	—	—	0.21	—	—
	99.98	100.60	100.06	100.01	100.37	99.79	100.38	100.47	97.93
			BaO, 0.05						

1. Rokeby Type, basic iddingsite-oligoclase-basalt, from midway between Rokeby and Bellerive. *Analyst*: W. St. C. Manson.
- A. Limburgite, No. 3 Quarry, Woodend, Victoria (Newer Volcanic Series). (*Bull. Geol. Surv. Vic.*, No. 24, p. 28, 1912.)
2. Iddingsitized nepheline-basanite, One Tree Point, Sandy Bay, Hobart. (Aurousseau 1926.)
3. Limburgite, Llewellyn, near Avoca. *Analyst*: W. St. C. Manson.
4. Olivine-nephelinite, top flow at Derby (road cutting). *Analyst*: W. St. C. Manson.
5. Melilite-basalt, Shannon Tier. (Paul 1906, p. 305.)
6. Monticellite-nepheline-basalt, Shannon Tier. (*Ibid.*, p. 312.)
7. Melilite-fassinite, Shannon Tier. (Erdmannsdorffer 1928.)
8. Melilite from the melilite-basalt (No. 5) of Shannon Tier. (Paul 1906, p. 305.)

In addition to these specimens in which the olivine is more or less completely iddingsitized, there are occasional occurrences of this type of basalt in the Midlands and in northern Tasmania, in which the olivine is unaltered.

A specimen of the rock occurring about midway between Rokeby and Bellerive, adjacent to the road, was selected as representative, and analysed. The analysis (Table 6, No. 1) shows that for a basalt with so sodic a felspar, the composition is unusual. The high Fe_2O_3 content reflects the abundant iddingsite. The general resemblance to Analysis No. 2 of Table 6 suggests close relationship to the iddingsitized nepheline-basanite of Sandy Bay. The Rokeby basalt is slightly the richer in silica and alumina, and distinctly richer in magnesia; but it is poorer in lime and soda, and particularly in potash. There is also some resemblance to the limburgite from Llewellyn, near Avoca (Table 6, No. 3), but this is a more basic rock, with less silica and alumina, and much more magnesia than the Rokeby basalt. It would appear that the Rokeby basalts represent an intermediate stage in the differentiation of these basic and ultrabasic types. The nearest match in chemical composition is provided by a limburgite from Woodend in Victoria (Table 6, Analysis A).

Limburgites and Limburgite-basalts

Limburgite has been recorded from the vicinity of Burnie,⁽²³⁾ and further occurrences were found during this study at Llewellyn, near Avoca, at a point 20 miles south of Somerset, about seven miles south of Burnie on the road to Ridgely, at the northern end of the Green Hills on the Stanley Peninsula, and about eight miles west of Smithton.

These rocks consist of microphenocrysts of olivine, generally fresh, and frequently idiomorphic, in an extremely fine-grained groundmass of minute prisms of brown pyroxene, uniformly distributed granules or octahedra of iron ore, and a considerable amount of glass. Occasional microlites of felspar are present, and in some sections there are crystals in the groundmass which show very low double refraction, and appear to be nepheline.

The specimen from Llewellyn was analysed with results shown in Table 6, No. 3. The distinctive features of the analysis are the high magnesia figure, and the high soda, indicating a close relationship with the olivine-nephelinites (Table 6, No. 4) and with the melilite-basalts of Shannon Tier (Table 6, No. 5).

Rocks closely resembling the limburgites, but which are better called limburgite-basalts, because they contain a small proportion of plagioclase microlites, have been found at a number of localities: two and a half miles from Forth on the Forth-Wilmot road; at Rosebery; New Norfolk; near Castra; four miles from Ulverstone on the road to Castra; at Interlaken; on Flinty Top, near Oatlands; and at Don Heads.

In these rocks the pyroxene occasionally occurs as idiomorphic microphenocrysts, while in the rocks from Don Heads the occasional felspar crystals are unusually large. Flow structure is present in the Interlaken and Ridgely specimens, and the specimen from Flinty Top contains an inclusion of dolerite.

Olivine-nephelinites and Basanites

Nepheline-basanites occur at One Tree Point, Sandy Bay near Hobart, and at the Nipples, west of Anthill Ponds, in the Midlands; olivine-nephelinites outcrop at the Old Man's Head, near Lake Crescent, on Flat Top, near Oatlands, as the upper and middle lava flows at the Briseis mine, Derby, and near Ledgerwood and

Branxholm, where they form extensive flows filling the old Ringarooma Valley, at Scottsdale, and on the west side of the Forth Gorge, about two miles from Wilmot on the road to Sheffield.

The Sandy Bay rock was first described as a fayalite-basalt,⁽²⁶⁾ but was later shown to be a nepheline-basanite in which the olivine had been altered to iddingsite.⁽¹⁾ The earlier analysis of White and McLeod⁽²⁶⁾ is inaccurate, and is not quoted. The later analysis of Aurousseau⁽¹⁾ is shown in Table 6, No. 2. The general resemblance of this analysis to that of the melilite-fasinite of Shannon Tier (Table 6, No. 7) is evident.

The olivine-nephelinites vary somewhat in grain size, but are all fine-grained, and they have a distinctive texture in thin section (Pl. III, fig. 1). They consist of microphenocrysts of olivine, sometimes partially or completely replaced by iddingsite, set in a felted groundmass of short prisms of greenish to brownish pyroxene, small olivine grains, numerous relatively coarse octahedra of iron ore, idiomorphic prisms of apatite, and an abundant mesostasis of nepheline or feldspathoidal glass. In some sections the nepheline occurs as well-shaped crystals, uniformly distributed throughout the groundmass (Pl. III, fig. 2).

The olivine is present in crystals of two generations. It forms microphenocrysts about 0.1 mm. long, which are idiomorphic, with a tendency to be corroded. It also occurs as idiomorphic crystals, about 0.02 mm. diameter in the groundmass. The pyroxenes occur as prisms and needles with an extinction angle of about 45° parallel to the prism face, and are restricted to the groundmass, with an occasional phenocryst the size of the olivine crystals. In one section a corona of pyroxene prisms encloses a partially dissolved grain of quartz. The iron ores occur as rectangular or angular grains of a size comparable with the other groundmass constituents. Apatite occurs as fine needles in the feldspathoidal base, and as prominent prisms larger than the pyroxene prisms.

In some sections there is an abundant mesostasis of colourless glass, interspersed with crystals of nepheline. In others the glass is largely replaced by nepheline, which in some occurs as idiomorphic crystals. This is particularly so in the specimens from the Forth Gorge, Scottsdale and the top flow at Derby.

The latter rock was selected as typical, and an analysis made of it (Table 6, No. 4). Comparison with the other analyses of Table 6 reveals its close affinities with the limburgites and the melilite-basalts of Shannon Tier.

Melilite-fasinite

An occurrence of melilite-fasinite at Shannon Tier has been described by Erdmannsdorfer and Nieland,⁽⁹⁾ and from thin sections of the Mines Department of Tasmania it would appear that it came from the hill known as the Beehive. The fasinite is a coarse-grained rock, consisting of laths of black pyroxene up to 2 cm. long, in a grey-white zeolite-bearing groundmass. The pyroxene is a brown titanaugite, with corroded cores of colourless augite, and rims of deep-green aegirine-augite. It contains inclusions of magnetite, apatite, olivine, nepheline, melilite and perovskite. The olivine is optically positive and has a composition about Fa_{17} . It occurs as occasional rounded grains about 2 mm. across, and shows partial alteration to serpentine, iddingsite and chlorite. The melilite occurs as grains and tablets about 3 mm. across. It is uniaxial, negative, with refractive indices $w = 1.632$, $e = 1.623$, and is yellow with weak pleochroism. It is idiomorphic against the enclosing pyroxene. Some of the melilite is altered to a greenish serpentine-like substance. Perovskite and apatite occur in some abundance, the

latter in prisms up to 2 mm. long. There are also subordinate amounts of red-brown biotite, a soda-hornblende, tentatively identified as lavenite, rohnite(?) and cancrinite.

The remainder of the rock, the groundmass, consists of zeolites, chiefly hydro-nephelinite, and natrolite, with minor amounts of thomsonite, phillipsite and desmine, derived from the alteration of nepheline.

It seems likely from the description that this rock is a 'pegmatite' in a somewhat finer-grained melilite-fasinite, of generally similar composition. The analysis of the finer-grained melilite-fasinite is quoted in Table 6, No. 7. The general resemblance of the analysis to that of the nepheline-basanite from Sandy Bay (Table 6, No. 2), as distinct from that of the olivine-nephelinite (No. 4), agrees with Lacroix's⁽¹⁶⁾ contention that the fasinites are to be correlated with the basinites—'La forme microlitique de la fasinite serait une basanite tres riche en nepheline.' Johannsen⁽¹¹⁾ relates them to the monchiquites, but this is not borne out by the limburgite analysis (No. 3).

It may be noted that R. A. Daly⁽²⁾ mistakenly refers to this rock as a plutonic rock.

Melilite-basalts

Several small plugs of melilite-basalts and related rocks occur on Shannon Tier. Paul⁽²⁰⁾ in 1906 described a melilite-nepheline-basalt and a nepheline-eudialyte-basalt from this locality. Tilley⁽²²⁾ in 1928 re-examined the latter, and reported that the identification of eudialyte was incorrect. He also established that the unidentified mineral reported by Paul as probable Ca_2SiO_4 , and previously referred to by Tilley⁽²¹⁾ as 'shannonite,' was in fact monticellite, $(\text{CaMg})_2\text{SiO}_4$, so that he renamed the rock a monticellite-nepheline-basalt.

Melilite-nepheline-basalt forms the small plugs known as the Ant Hill and the Beehive. It is a dense greenish-black rock showing phenocrysts of olivine. It has a granular hypidiomorphic texture and consists of olivine, pyroxene, melilite, nepheline, perofskite and magnetite. The olivine occurs as small idiomorphic phenocrysts, but is relatively inconspicuous compared with the melilite, which forms numerous elongated tabular or prismatic crystals ramifying the rock (Pl. III, figs. 3, 4). It is optically negative, with straight extinction, and is studded with minute inclusions of magnetite, perofskite and pyroxene. Paul separated some of the melilite, using Thoulet's solution, and had an analysis made of the acid-soluble portion of the powder, thus rejecting the included minerals other than apatite. This analysis is shown in Table 6, No. 8.

The pyroxene occurs only as small sparsely distributed prisms. The perofskite occurs as irregular, late-formed grains of a reddish-yellow colour, with anomalous double refraction. Nepheline is present as quadrate and hexagonal sections in some abundance (Pl. III, fig. 4) and there is a considerable amount of coarsely crystalline apatite and magnetite. Paul's analysis of this rock is shown in Table 6, No. 5, and reveals its close resemblance to the olivine-nephelinites and the limburgites.

The monticellite-nepheline-basalt is a fine-grained, hypidiomorphic granular rock, consisting of olivine, monticellite, nepheline, titanaugite, perofskite, apatite, magnetite, (?)sodalite, and colourless mica partly altered to chlorite. The monticellite occurs as rims (chadakrysts) around cores of olivine (oikakrysts). The pyroxene is more abundant than in the melilite-basalt, as in the perofskite, and both are coarser-grained. An analysis of this rock, presented by Paul, is shown in Table 6, No. 6. It shows that it is distinctly richer in alumina and lime and poorer

in magnesia and titania, and in alkalis, than the melilite-basalt. Except as regards titania, its resemblance is towards the melilite-fasinite, so that it lies more or less intermediate between the two.

Conclusions

This study indicates that the Cainozoic basalts of Tasmania are all olivine-basalts, ranging in composition between two extremes—

- (a) a group of basalts with about 44 per cent SiO_2 , 14 per cent Al_2O_3 , and $\text{MgO}:\text{CaO}$ about 11:9, namely the *titanaugite basalts*, which correspond to the olivine-basalt magma type, as defined by Kennedy,⁽¹⁴⁾ being, if anything, more basic than it;
- (b) a group of basalts with about 50 to 51 per cent SiO_2 , 14 to 15 per cent Al_2O_3 , and $\text{MgO}:\text{CaO}$ about 8:8.5, namely the *basalts with black glass*, which are intermediate in composition between the olivine-basalt magma type and the tholeiitic magma type, as defined by Kennedy.⁽¹⁴⁾

Intermediate between these two extremes is a widespread group of *basalts with green glass* (group c).

As may be seen from Table 7, there is a considerable resemblance between the titanaugite basalts of group (a) and the Older Volcanic Magma Type of Victoria, on the one hand, and between the basalts with black glass (group (b)), and the Newer Volcanic Magma Type of Victoria, on the other, the latter resemblance being the closer. The group (c) basalts also have their counterparts in the widespread Trentham basalts of the Newer Volcanic Series of Victoria, and in the Flinders Type of the Older Volcanic Series in that State. However, despite the tholeiitic affinities of the group (b) basalts, there is a clear distinction both in chemical and mineralogical composition between the various olivine-basalts and the Mesozoic dolerite magma of Tasmania, which was truly tholeiitic.⁽⁷⁾

TABLE 7
Basaltic Magma Types in Tasmania and Victoria

	<i>Tasmanian Magma Types</i>			<i>Victorian Magma Types</i>	
	Olivine titanaugite- basalt Type	Olivine- augite- basalt Type	Dolerite Magma Type	Older Volcanic Magma Type	Newer Volcanic Magma Type
SiO_2	44	50	52.5	46	50
Al_2O_3	14	14.5	16.2	15.5	15
$\text{FeO}, \text{Fe}_2\text{O}_3$	12.0	11.5	8.7	11.5	11.5
MgO	11	8	6.6	8	8.5
CaO	9	8.5	11.3	8	8.5
Na_2O	2.6	2.6	1.6	2.9	3.0
K_2O	1.2	0.7	0.9	1.4	1.2

In Victoria, titanaugite-basalts are sufficiently characteristic of the Older Volcanic Series to serve as 'markers,'⁽⁴⁾ and the iddingsite-basalts with black glass (Footscray and Malmsbury Types) are equally characteristic of the Newer Volcanic Series. The basalts with green glass in the two series match too closely to permit their classification as Older or Newer Volcanic on petrological grounds, and can be

classed only according to their association with more characteristic types of basalt, or on stratigraphic evidence. Such a relation does not hold in Tasmania.

Fig. 1 shows the approximate localities of the specimens studied in terms of the main basalt types, and hence the relative distribution of these main types, assuming that the sampling has been adequately random. The map reveals some intermingling of types, but it also shows:

- (a) a predominant association of titanaugite basalts (Hampshire, Burnie, Deloraine, Bransholme types) and basalts with green glass (Mersey, Waratah types) in the north-central and north-western areas;
- (ii) a predominance of basalts with black glass (Midlands, Bridgewater, Ouse types) extending from Launceston through the Midlands (strongest development) to the south-east;
- (iii) a small association of basic oligoclase-basalts intermingled with (ii) in the south-east.

The olivine-nephelinites are associated with titanaugite basalts at Forth, Scottsdale, Ledgerwood and Derby, and, together with limburgites, nepheline-basanites and melilite-basalts, accompany the basalts with black glass in the Midlands and south-east.

It thus appears, on petrological grounds alone, that in Tasmania either (a) there were, as in Victoria, two major periods of basaltic volcanicity, deriving from source magmas of different composition, which gave rise to petrologically distinct basaltic types, or (b) that contemporaneous extrusions developed from two or more co-existent basaltic magmas, occurring either in separate reservoirs or as layered magma differentiated within a single magma reservoir of considerable dimensions.

The distribution of the basalt types relative to one another, and to sediments of known age, such as the Miocene beds at Wynyard, and the Launceston and Derwent Basins, favours the second alternative. In this connection the relationships of the basalts in the area between Breadalbane, Perth and Evandale to the sediments of the Launceston Basin is critical. These basalts include typical titanaugite basalts, as at Perth, and if, as appears, they overlie the Miocene sediments, then some at least of the titanaugite basalts are post-Miocene. Basalts of the Midlands Type at St. Leonards and near Nile are definitely younger than these sediments, and the Bridgewater and Ouse basalts are younger than similar sediments in the Derwent Basin. Petrological studies, therefore, provide no criteria for distinguishing between pre-Miocene and post-Miocene (Pliocene) basalts in Tasmania. They do, however, indicate the more or less contemporaneous existence of the two extreme basalt magmas in close proximity to one another.

Relationship between Tertiary Basalts and Jurassic Dolerites

A comparison of the distribution of the Tertiary basalts and the Jurassic dolerites shows that the basaltic magma must have underlain almost the same area as the dolerite magma, or possibly a wider area, since basalts occur on Flinders Island, although the volume of basalt extruded was probably less than one-quarter the volume of dolerite magma drawn off from its source reservoir. In each period, therefore, a more or less continuous sheet or body of magma underlay an area of the order of 15,000 square miles; and unless it is assumed that the dolerite intrusions completely drained their source reservoir, some layered arrangement in depth of the two magmas must be pictured.

These crustal layers must normally be solid. If they were fluid, the tholeiitic layer would need to be uppermost in Jurassic time, to permit the intrusion of so homogeneous a tholeiitic magma as the dolerite, on so wide a scale; and a fluid layering with tholeiitic magma at the top is not compatible with the early extrusion of olivine-basalt magma in the Tertiary.

These successive periods of igneous activity must have resulted, therefore, from the melting of sheets of these crustal layers. The probability is that the tholeiitic layer overlies the olivine-basalt layer, and that the vigorous erosion that followed the dolerite intrusions was accompanied by an isostatic adjustment that by Tertiary time had raised the tholeiitic layer above the critical level for melting, so that it remained solid while the deeper-lying olivine-basalt layer melted. The more or less contemporaneous extrusion in Tertiary times of undersaturated olivine-basalt, and olivine-basalt with tholeiitic affinities, together with intermediate types points to a gradational layering in the olivine-basalt layer of the crust, presumably an upward transition to the tholeiite layer.

There is a parallel between this picture and the crustal layer hypothesis evolved by Kennedy and Anderson⁽¹⁵⁾ and recently invoked by MacGregor⁽¹⁷⁾ to explain the sequence of extrusions during the Carboniferous-Permian volcanicity in Scotland. They postulate that basaltic rocks originate from sheet-like reservoirs of fluid magma almost constant in depth, and extending for long distances, in many instances hundreds of miles, at certain critical levels in the earth's crust. The reservoirs are pictured as originating at different times and at different levels by the fusion of crustal layers of different composition, distributed as indicated in Fig. 2. The tholeiitic layer is thought to result, possibly, from contamination of original alkaline olivine-basalt magma by the granitic layer.

Crustal Layering in a Non-Orogenic Region
(after MacGregor (1948))

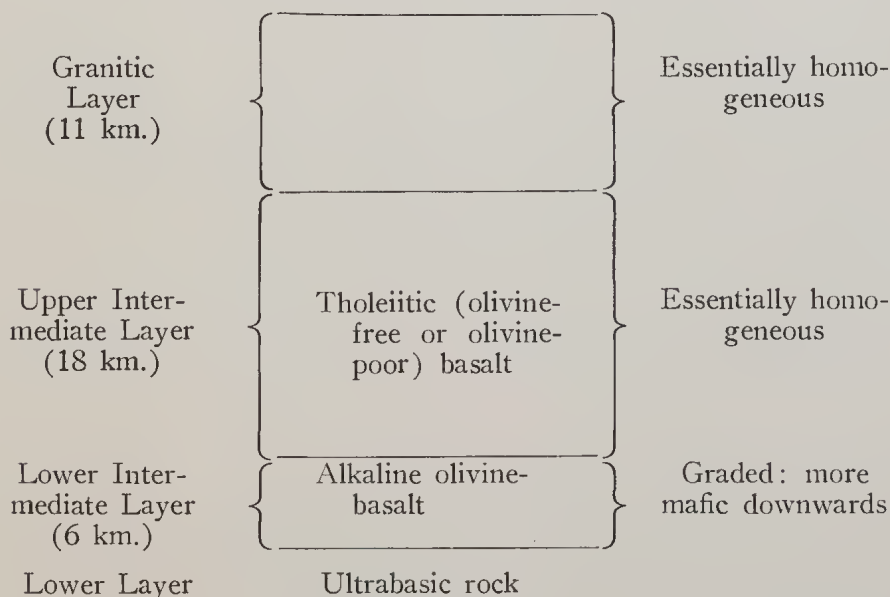


FIG. 2.

Significance of Green and Black Glasses

The association of green glass with undersaturated olivine-basalts, and of black glass—that is, glass carrying innumerable globules and trichytes of iron ore—with basalts showing tholeiitic affinities, does not appear to be fortuitous. Similar associations are found in the basalts of the Newer and Older Volcanic Series in Victoria, and tholeiites proper are characterized by such black glass. It is a feature of tholeiites that they show a higher FeO/MgO ratio than olivine-basalts; and it would appear that the increased relative proportion of iron is not wholly accommodated in the normal ferromagnesian silicates, but tends to accumulate to some extent in the residual magma, in other words the glass. Black glass, then, is probably an indication of strong tholeiitic affinity, and may also be regarded as indicating that the basalt containing it is derived from a magma that has undergone some degree of differentiation, resulting from impoverishment in magnesia.

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Description of Plates

PLATE I

- Fig. 1.—Ouse Type, analysed specimen. $\times 20$, ordinary light. Glassy basalt consisting of phenocrysts of olivine, which may be serpentinized, and microphenocrysts of plagioclase, about the size of groundmass laths for a holocrystalline basalt, set in a black intersertal glass with radially arranged or plumose trichytes of augite.
- Fig. 2.—Bridgewater Type, analysed specimen. $\times 20$, ordinary light. Phenocrysts of olivine, in a groundmass of plagioclase laths, granular augite, and intersertal black glass. There is some tendency for the plagioclase to form occasional microphenocrysts.
- Fig. 3.—Bridgewater Type. $\times 20$, ordinary light. Phenocrysts of olivine in a groundmass of plagioclase laths, granular to prismatic augite, and black glass.
- Fig. 4.—Midlands Type, analysed specimen. $\times 20$, ordinary light. Shows typical texture, with abundant colourless to slightly brownish augite, sub-ophitic towards plagioclase laths (labradorite), and enclosing phenocrysts of olivine with rims of iddingsite. Iron ores tend to be lath-shaped, and a little dark glass may be present in the interstices. The rock tends to be vesicular.
- Fig. 5.—Mersey Type, analysed specimen. $\times 20$, ordinary light. A relatively coarse-grained example, with intergranular texture, and tending to contain more or less intersertal green glass. The groundmass of plagioclase laths, granular augite, iron ore and glass encloses phenocrysts of olivine, and occasional inchoate phenocrysts of augite and plagioclase.
- Fig. 6.—Waratah Type, analysed specimen. $\times 11$, ordinary light. Phenocrysts of olivine, augite and plagioclase in an intergranular to intersertal groundmass of labradorite laths, augite granules, iron ore, and green glass.

PLATE II

- Fig. 1.—Hampshire Type, analysed specimen. $\times 11$, ordinary light. Characteristic coarse rosette of zoned titanaugite crystals, forming macrophenocrysts in an intergranular olivine-titanaugite-basalt.
- Fig. 2.—Burnie Type, analysed specimen. $\times 20$, ordinary light. Shows olivine phenocrysts, slightly resorbed, and a typical patch of ophitic titanaugite and plagioclase laths, with parallel arrangement from flowage. The lens-like shape of the ophitic titanaugite areas is particularly obvious with crossed nicols.
- Fig. 3.—Deloraine Type. $\times 20$, ordinary light. An olivine-titanaugite-basalt in which the olivine phenocrysts are more clustered than in the Burnie Type, and the ophitic titanaugite is gathered into larger crystals, with fewer and random oriented plagioclase laths, leaving larger and more prominent areas of colourless felspar laths between.
- Fig. 4.—Branxholm Type. $\times 20$, ordinary light. Microphenocrysts of olivine and labradorite in an intergranular groundmass that contains a high proportion of brown to violet augite, and a little coarsely crystalline magnetite. The abundance of augite in the groundmass gives the rock a dark appearance, even in thin section.
- Fig. 5.—Branxholm Type. $\times 20$, ordinary light. A coarse-grained variation, approaching an olivine-dolerite in texture, and consisting of phenocrysts of olivine and plagioclase in an intergranular groundmass of coarse plagioclase laths and coarse granules of brownish augite or titanaugite. In places the felspar is somewhat analcitized, and colourless glassy areas occur in which there is a little greenish chlorite and skeletal iron ore.
- Fig. 6.—Rokeby Type, analysed specimen. Basic oligoclase-basalt, $\times 35$, ordinary light. Shows microphenocrysts of olivine completely altered to iddingsite in a microlitic intergranular groundmass of oligoclase laths and augite.

PLATE III

- Fig. 1.—Olivine-nephelinite, analysed specimen. $\times 35$, ordinary light. Typical texture of a fine-grained olivine-nephelinite, showing microphenocrysts of olivine in a groundmass of nepheline crystals, micro-prisms of greenish to colourless augite, and squarish grains of iron ore.
- Fig. 2.—Olivine-nephelinite, analysed specimen. $\times 135$, ordinary light. Central part of field of Photo. 16, magnified to show the texture of the groundmass, and the inclusions in the nepheline crystals.

- Fig. 3.—Melilite-basalt. $\times 35$, crossed nicols. Shows two bladed crystals of melilite, with numerous small inclusions, and phenocrysts of pyroxene in an intergranular groundmass.
- Fig. 4.—Melilite-basalt. $\times 35$, ordinary light. Same field of view as Fig. 3, showing the abundant nepheline and granular iron ore in the groundmass. (Note that Fig. 4 has been inadvertently rotated during mounting.)
- Fig. 5.—Point of eruption, about one mile north of the Hampshire Railway Station, and just east of the railway line. The flow issued to the south-west. This is the type locality of the Hampshire Type olivine-basalt.